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FACILITY FORM 602

Sequential Probabilities and the Learning and Retention of Tracking Skill[1]

(Paper presented at the Midwestern Psychological Association Meeting, Chicago, Illinois, May 6, 1966)

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In prior studies of task organization variables in tracking skill, we have defined task predictability in terms of the proportion of fixed target events in an irregular step-function input. Thus, for example, a predictable task consisted of a sequence of 12 target events, with the same sequence repeated throughout training, whereas degrees of unpredictability were achieved with the same basic sequence, but with every third, every fourth, or every sixth target selected anew and randomly on each repetition.

The results of these prior studies indicated that the random, or unpredictable, target events interfered disproportionately with tracking performance, as reflected in integrated error scores. For instance, with as few as 1/3 of the targets unpredictable, performance was no better than with a completely random input, except after rather extensive practice. Subjects appeared unable to make use of the redundancies in the predictable target events, that is, they failed to show evidence of perceptual anticipation of the predictable targets.

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The purpose of the present study was to determine whether task predictability, defined alternatively in terms of second-order probabilities among target events, would affect tracking performances in a similar way. In addition, we proposed to investigate the response strategies which subjects developed to cope with varying degrees of uncertainty in a sequential tracking task. With repetitions of the same choice situations and with unequal probabilities of alternative target events, it was possible to compare our results with studies in which subjects make discrete responses in predicting stimulus events. In such studies response patterns are usually described as "matching", when the subject's response choices are proportional to the signal probabilities, or as "maximizing" when the response corresponding to the most probable signal is always chosen. However, when responses are not restricted to discrete categories, but are free to vary along a continuum, other strategies are possible.

One class of alternative strategies may be labeled "compromising", or "minimizing maximum error per target event". The simplest of these would be "splitting the difference", that is, making an anticipatory response to a position midway between the two alternative target positions. A somewhat more sophisticated compromise would be to move to a position proportionately nearer the more probable event.

Finally, in the tracking situation, the subject might fail to anticipate, lagging behind the target until the uncertainty was reduced to zero by the occurrence of the event. Of course, this "strategy" has devastating results on integrated error scores in tracking a step-function input. In this study, such a strategy was discouraged by instructions to anticipate and through the feedback of error scores.

Our subjects were 80 male University students who were paid for their services. They were randomly assigned to six experimental conditions, as shown in Table 1 of your handout.

The tracking apparatus consists of a 5" CRT display, a control chair with a lateral arm control, pivoted at the elbow, and programming and scoring subsystems. For this study, both target and cursor were 1/2 inch vertical hairlines, overlapping by 1/8 inch at the X-axis of the CRT. Targets appeared at six positions 6/10 of an inch apart along the X-axis. A control movement of 11° arc resulted in a 1 inch displacement of the cursor.

The principle performance measure was integrated absolute error. It was obtained electronically by integrating the voltage differential between target and cursor inputs.

All subjects received irregular step-function inputs at one target per second. Trials were 48 seconds long, separated by 15-second rest intervals.

The six task conditions are summarized in your Table 1. The Predictable task consisted of a random order of the six target positions, repeated without pauses eight times per trial. The Random task consisted of a random sequence of the six target positions, 480 targets, or 10 trials, long. For each of the four intermediate tasks, the high probability targets were the same as the fixed targets of the predictable sequence, and the low probability alternatives were at the same locations for all groups. For greater generality of results, two sequences, A and B, were developed. Sequence A is shown in Figure 1 on your handout.

Subjects were assigned, 16 each, to the Predictable, .90-.10, .50-.50, and Random conditions, and 8 each to the .80-.20 and .70-.30 conditions. One-half of the subjects in the former groups received a secondary task at the retention session, which need not concern us here.

Instructions included an emphasis on rapid movement and anticipatory responding as effective strategies for minimizing error. Subjects were not told specifically which task they would receive. Error scores were integrated over 48 second trials and fed back during the rest intervals.

All subjects were given 20 trials daily for 4 days, then returned for 20 trials after an 8-day retention interval.

Now, for the results. Figure 2 on your handout presents the integrated error data for acquisition and retention. These data indicate that the predictable task resulted in the greatest reduction in error, followed, in order, by the probability and random tasks. However, there appears to be no difference between the Random, .50-.50, and .70-.30 tasks. Meanwhile, the .90-.10 and .80-.20 conditions resulted in some improvement, through relatively little as compared with predictable task. A 1 by 6 analysis of variance for the last block of training trials yielded a highly significant F and a Duncan's Test indicated that the Predictable task differed from all others and that the .90-.10 and .80-.20 tasks differed from all except the .70-.30 condition.

No significant error gains occurred as a result of the 8-day retention interval, except under the added secondary task condition.

Our analysis of response strategies began with an evaluation of lead-lag scores for selected trials. Three subjects with median error scores at the end of training were selected from each group. Their oscillographic records for acquisition Trials 1, 20, and 80 and Retention Trials 1 and 20 were hand-scored for leads and lags, defined as the discrepancy in time between target displacement and initiation of the primary movement.

The results are shown in Figure 3 of your handout. These data indicate that subjects in all conditions were lagging, on the average, by 100-200 milliseconds on Trial 1. By Trial 20 the subjects with the three most predictable inputs were leading. By Trial 80 leads averaged from 75 to 175 milliseconds. Meanwhile, under the three least predictable conditions, subjects continued to lag, but by far less than reaction time values by the end of training.

At retention, there were consistent reversions toward lagging, but recovery to terminal training levels was essentially complete by Trial 20.

Thus, while the integrated error data failed to indicate any losses over the retention interval, lead-lag scores indicated some changes in timing. In fact, lead-lag data on the recall trial appear very similar to that for Trial 20 of acquisition. Furthermore, it is evident that subjects in all groups were anticipating at least some proportion of the time by the end of training.

These data would seem to rule out "lagging", at least as a consistent strategy for coping with input uncertainties.

If you look again at Figure 1, you will see that our sequence "A" contained two types of choice situations. Notice that in going from target positions 1, 2, and 6, the high and low probability targets were in the same direction, while in going from positions 3, 4, and 5, the alternatives were in opposite directions. Thus, in the first instances subjects were faced with a choice between responses of different amplitudes, but the latter instances required a choice of direction, as well as of amplitude. Conceivably, then, timing in the two types of choice situations might be different, since a preparatory set as to direction of response is possible in one, but not in the other.

A comparison of the frequency of leads for the various choice situations provided support for this contention. The data for all subjects with the "A" sequence are shown in Figure 4. These data are for Trials 40 and 80 and are combined over the four probability tasks. Notice that the proportions of leads are higher in going from target positions 1, 2, and 6,--that is, when the choice was one of amplitude only.

Our final analysis was designed to provide evidence with respect to matching, maximizing, or compromising strategies. Again, taking only those instances when the subjects made anticipatory responses, we examined the response distributions for the four probability tasks, with the Predictable task serving as a control. For the directional choice situations, this analysis involved simply determining the proportions of responses initiated in the direction of each of the two alternatives. The results are summarized in Figure 5, for training trials 40 and 80. They indicate rather clearly that the subjects were matching the probabilities of the alternative target events when they made predictive responses. For example, subjects in the .90-.10 condition were anticipating the high probability target 89.8% of the time by Trial 80.

With alternatives in the same direction, the identification of response strategies is somewhat more complicated because it involves a comparison of response amplitudes. Nevertheless, it was assumed that maximizing would result in a distribution of response around the high probability target like that for the Predictable task, while matching should result in a bimodal distribution, with a proportionately smaller mode at the low probability target position. Similarly, compromising, as we conceived of it, should yield a unimodal distribution, centered some place between the two alternative positions.

The last figure on your handout shows distributions of responses for each task, combined for the three amplitude-choice situations in sequence "A". These data are plotted as deviations from the high probability target, with low probability targets to the right at 14 millimeter intervals.

These data indicate, first of all, a flattening of the response-generalization gradients and, secondly, a shift in the central tendency toward the low probability alternatives, with increases in event uncertainty. This shift in the distribution suggests that subjects were compromising, particularly in the absence of any clear evidence of bimodality. In fact, the median shifts for the .90-.10, .80-.20, and .70-.30 tasks are reasonably close to what would be predicted if the strategy was a "proportional, or matching, compromise".

To summarize briefly, then sequential probabilities appear to degrade overall tracking performance disproportionately to the amount of uncertainty they introduce, but it appears that subjects learn to cope with the uncertainties in a coherent, if not an optimal, manner. The strategy which subjects develop seems rather complex, including differential decision times consistent with the amount of uncertainty involved, probability matching when the choices are dichotomous, and compromise-matching when the choice is continuous.

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[1] This research was supported by the National Aeronautics and Space
Administration under NASA Grant No. NsG 606.

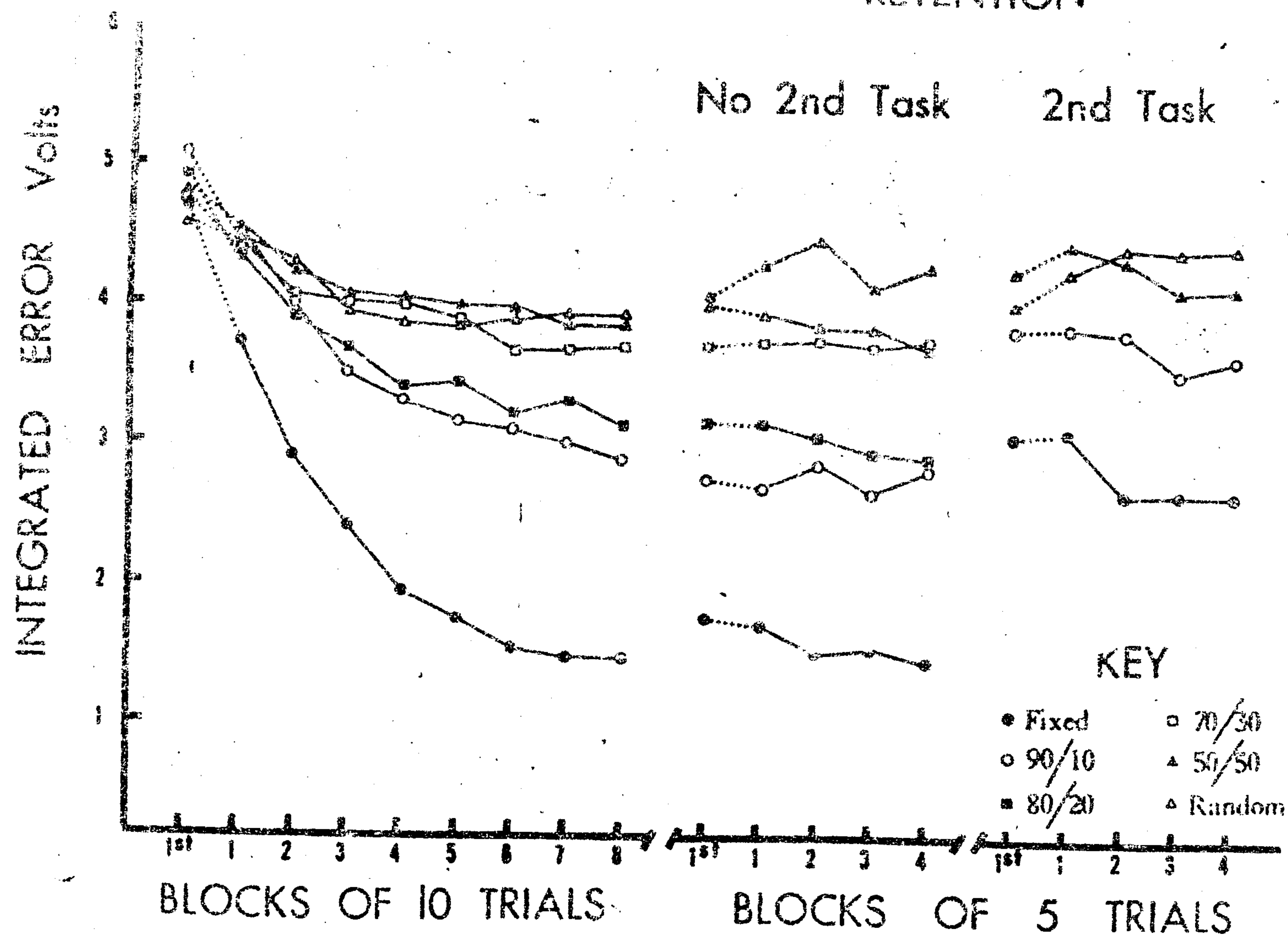

Fig. 2. Integrated error data.

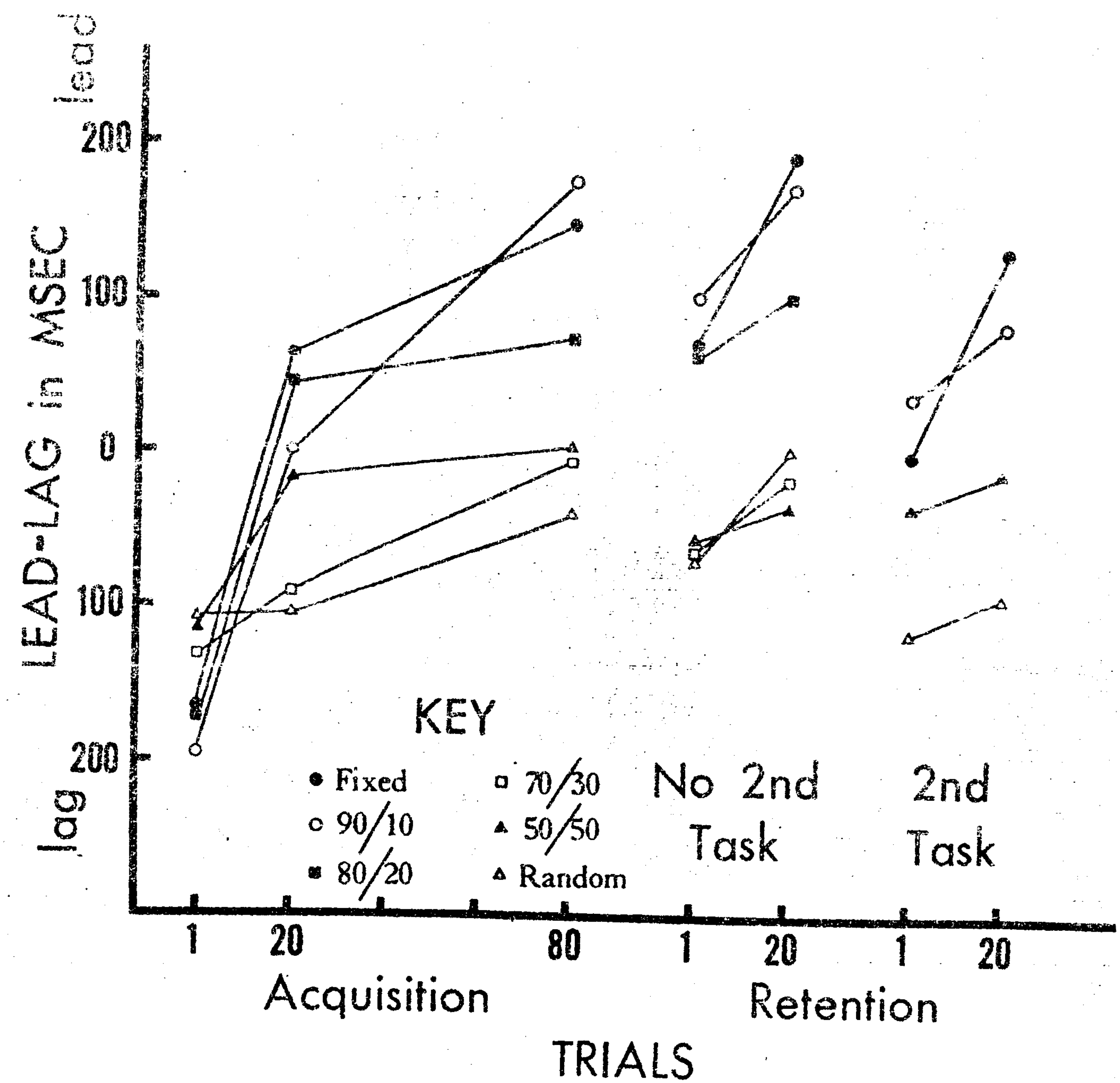
lead
200
100
0
100
200
lag
LEAD-LAG in MSEC
KEY
Fixed
90/10
80/20
70/30
50/50
Random
No 2nd
Task
2nd
Task
1
20
80
1
20
1
20
Acquisition
Retention
TRIALS

Table 1
Task Conditions

Task	N	Description	Bits/Signal
P*	16	fixed 6-target sequence	0
I-90/10*	16	2 alt./events; ps=.90/.10	.455
I-80/20	8	2 alt./events; ps=.80/.20	.720
I-70/30	8	2 alt./events; ps=.70/.30	.880
I-50/50*	16	2 alt./events; ps=.50/.50	1.000
R*	16	5 alt./events; ps=.20	2.320

*One-half the Ss in these conditions received secondary task at the retention session.

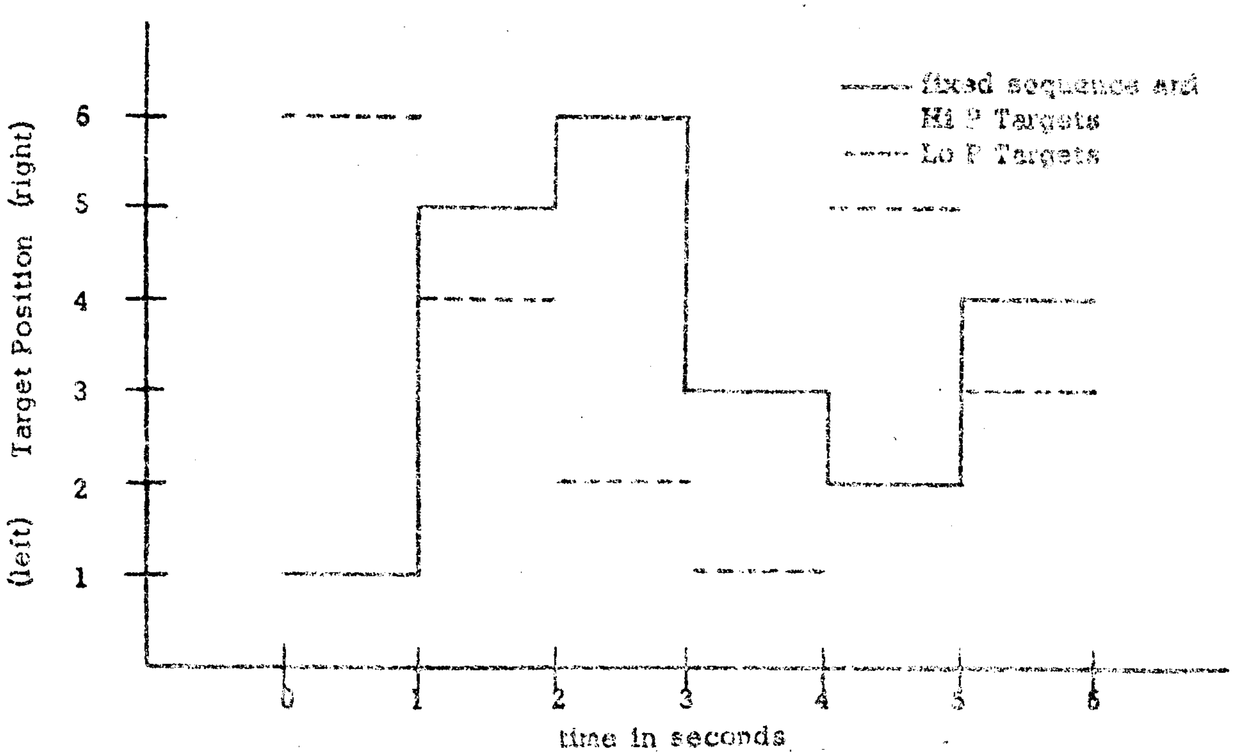

Fig. 1. Sequence "A" of two basic sequences used.

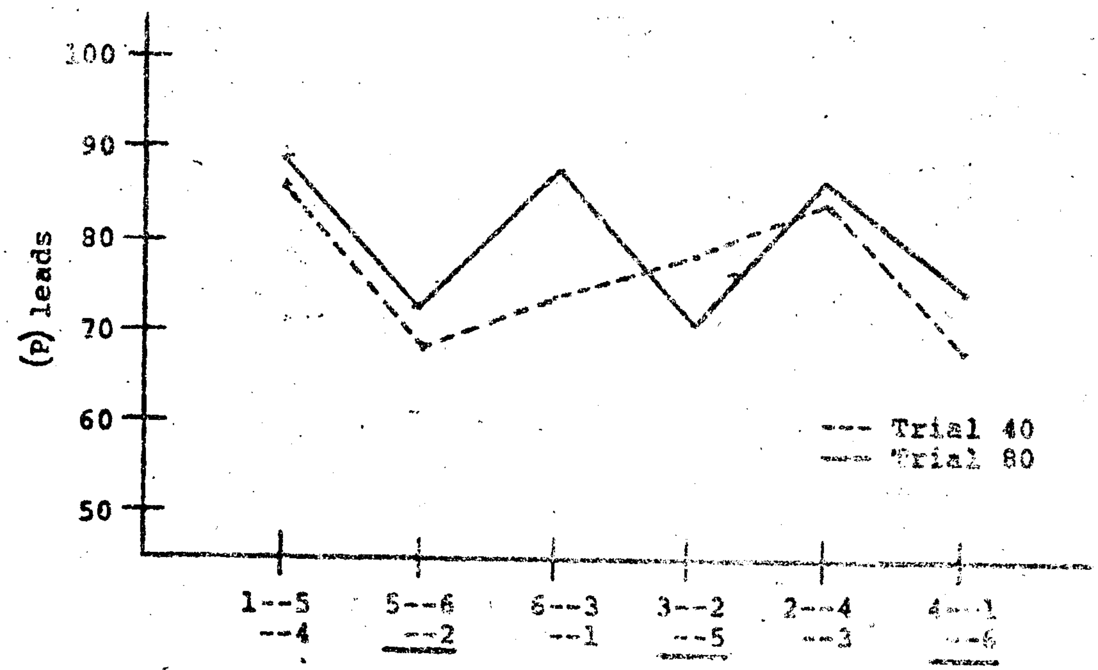

Fig. 4. Proportion of leads (including lags < 150 msec.) at each choice point. Data are pooled over the four Probability Tasks. (Sequence "A").

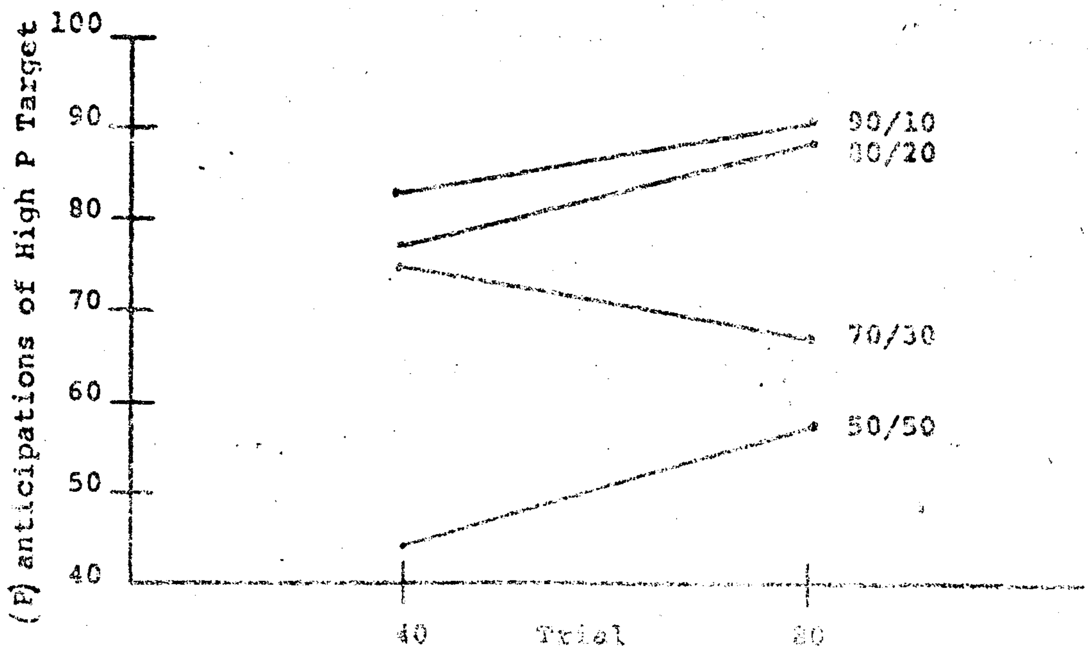

Fig. 5. Proportion of total anticipatory responses to the high probability target [illegible]

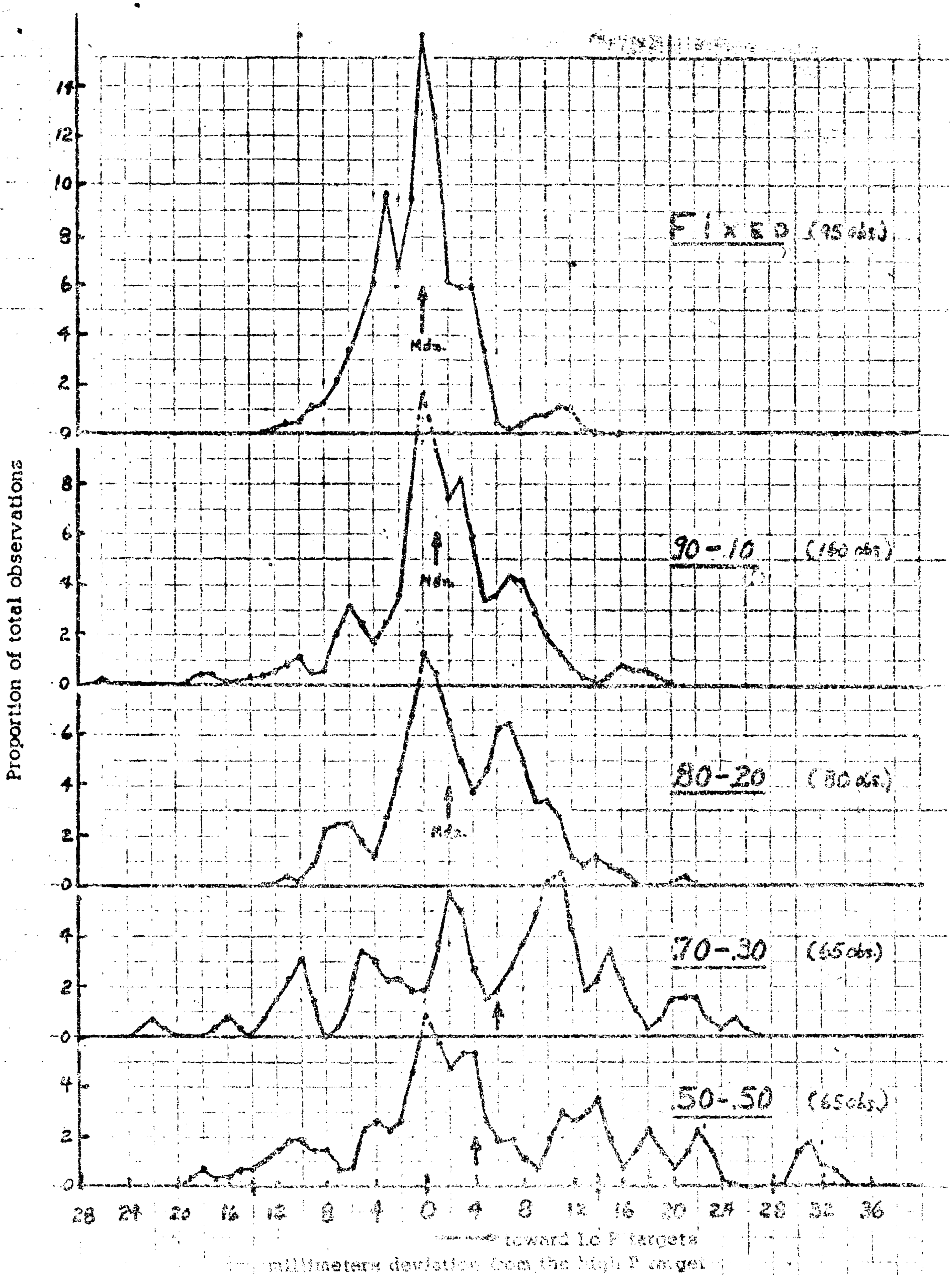

Fig. 6. Response distributions for the [illegible] choices, sequence "A"